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Particles and Pores: New transport and capture mechanisms

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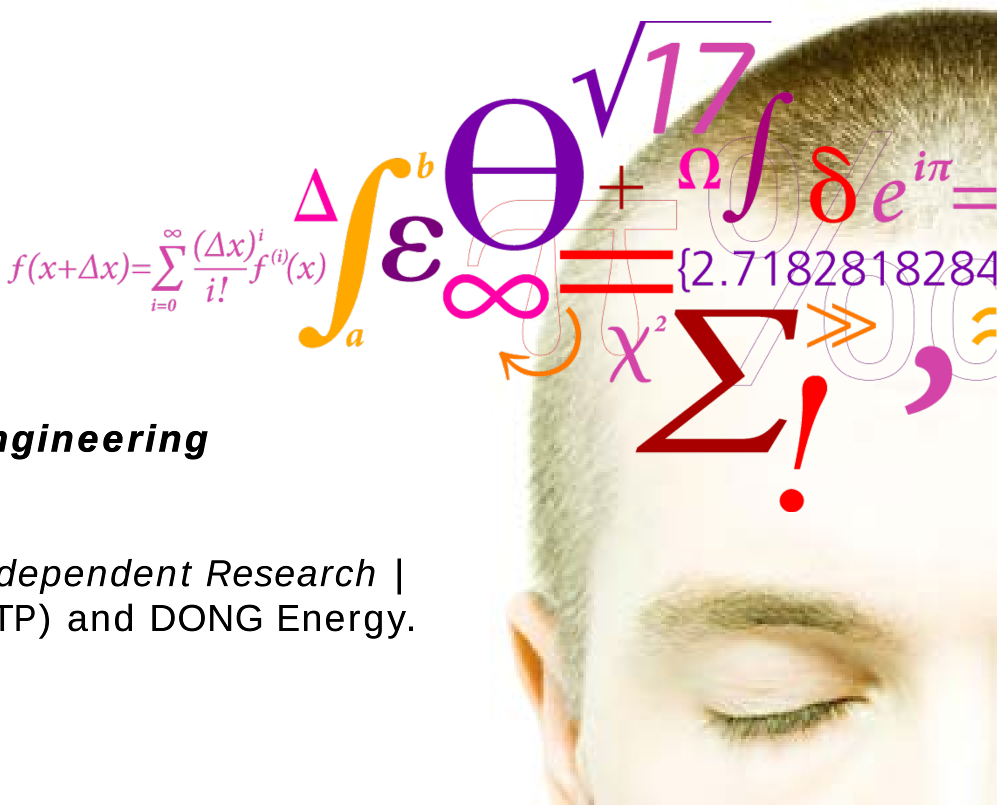
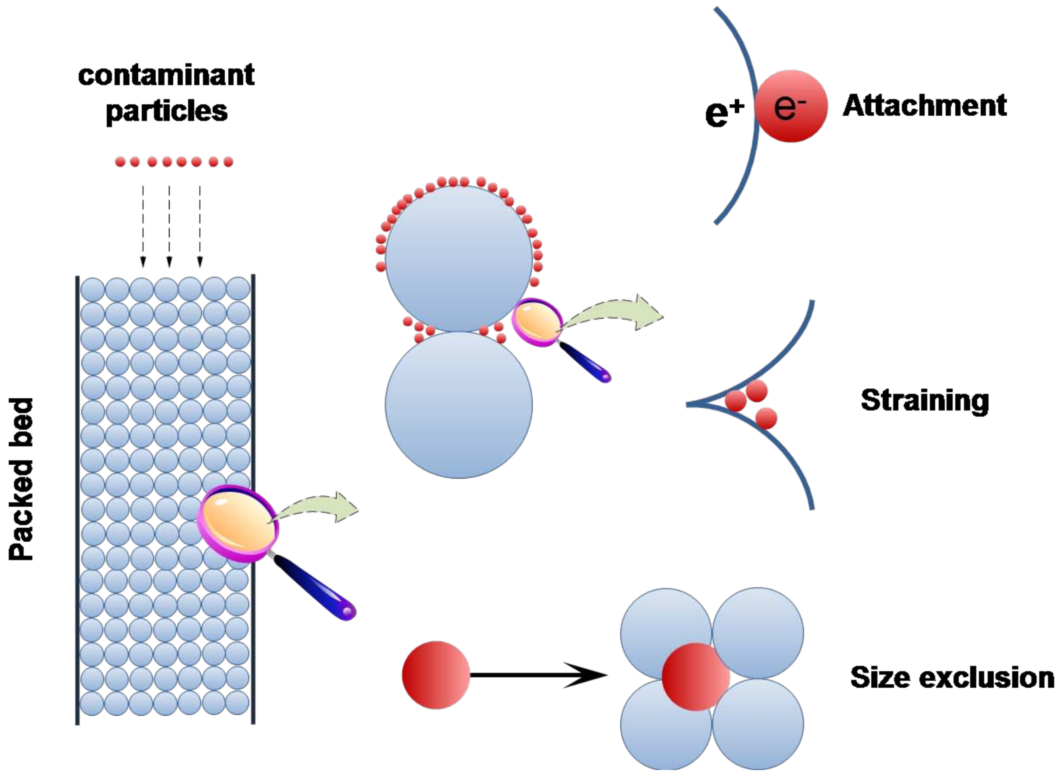
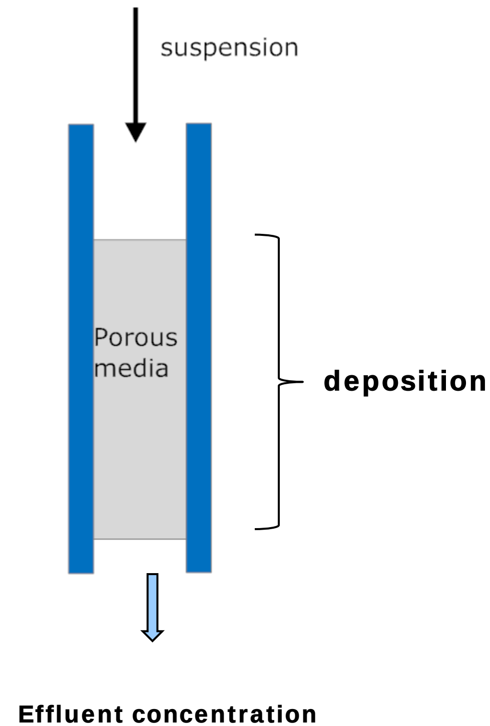
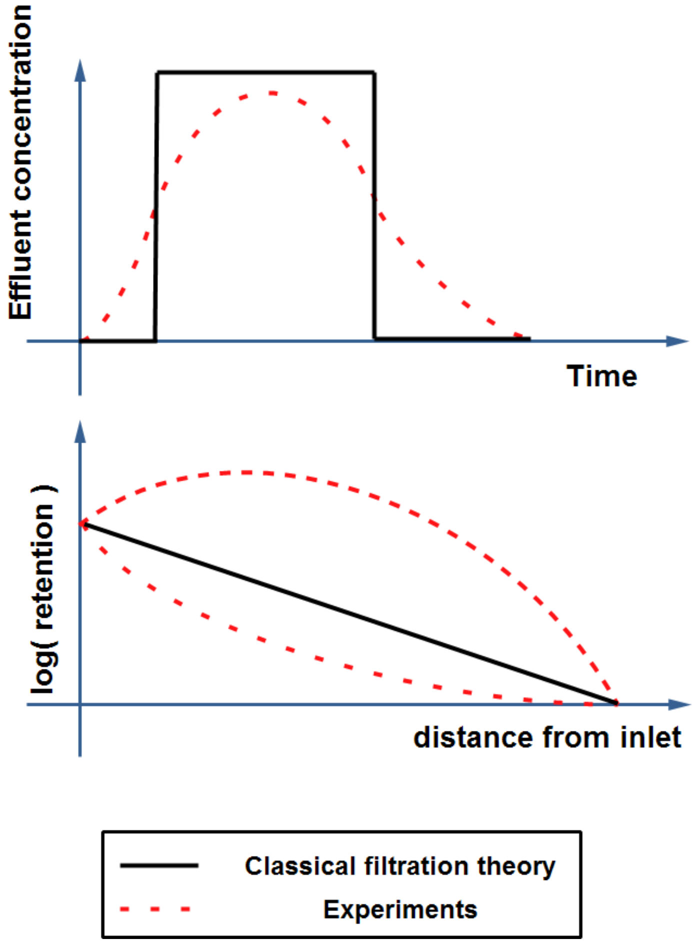


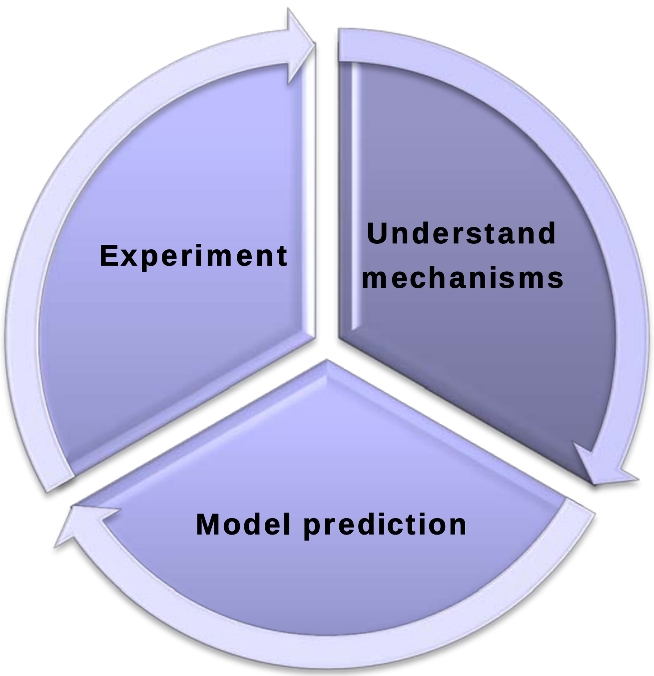
Deep bed filtration





Breakthrough and deposition profiles





Progress and outline

2009,Oct.~2010,May	• Non-Fickian transport • Hyper-exponential deposition
2010,May~2010,Aug.	• Release and migration of deposition • Non-monotonic deposition
2010,Aug.~2010,Dec.	• Uncertainty and sensitivity analysis • Models for non-Fickianity & hyperexponentiality
2011,Jan.~2011,Apr.	• Erosion of porous media • Fines migration in layer-cake reservoirs
2011,Mar.~2011,May	• Review of stochastic approaches to modeling suspension flow in porous media
2011,Apr.~2011,Jul.	• Developing software for waterflooding with solids filtration and injectivity decline

Task 01: Non-Fickian transport and Hyperexponential deposition

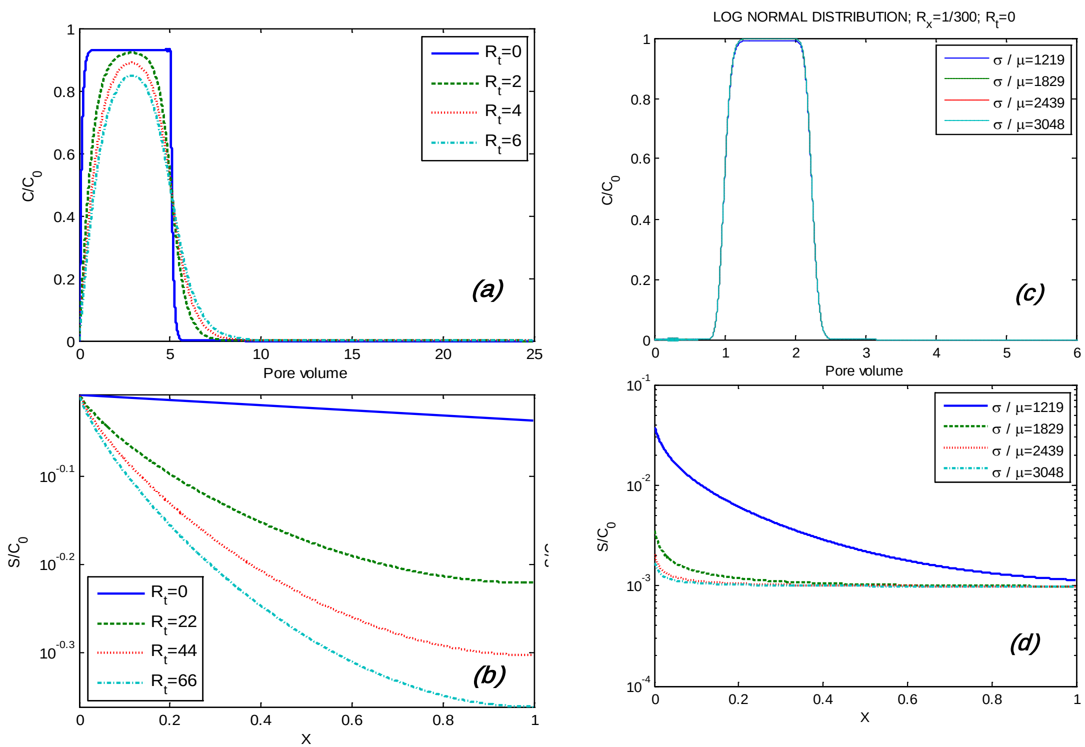
Elliptic equation[1,2]:

- Non-Fickian transport
- Median heterogeneity
- Temporal dispersion term

Distributed filtration coefficients:

- Poly-disperse suspension
- Log-normal distribution
- Power-law distribution
- Bimodal distribution

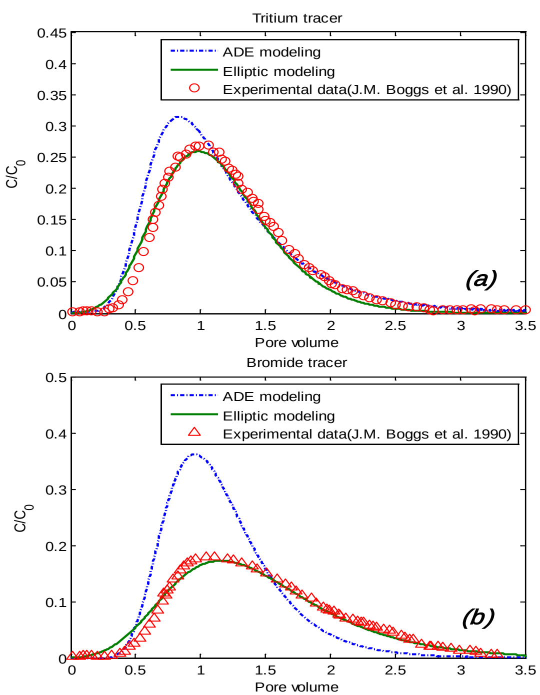
Deposition hyperexponentiality[3]



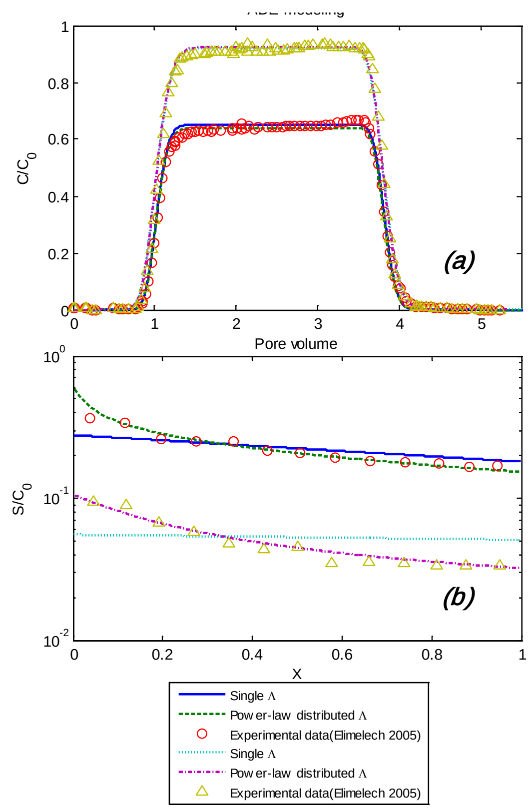
- Temporal dispersion→ hyperexponentiality
- Standard deviation→ hyperexponentiality

Deposition hyperexponentiality is attributed to non-Fickian transport(median heterogeneity) and particle population heterogeneity.

Comparison with experiments[3]



1. Natural Porous media
2. Tracer injection



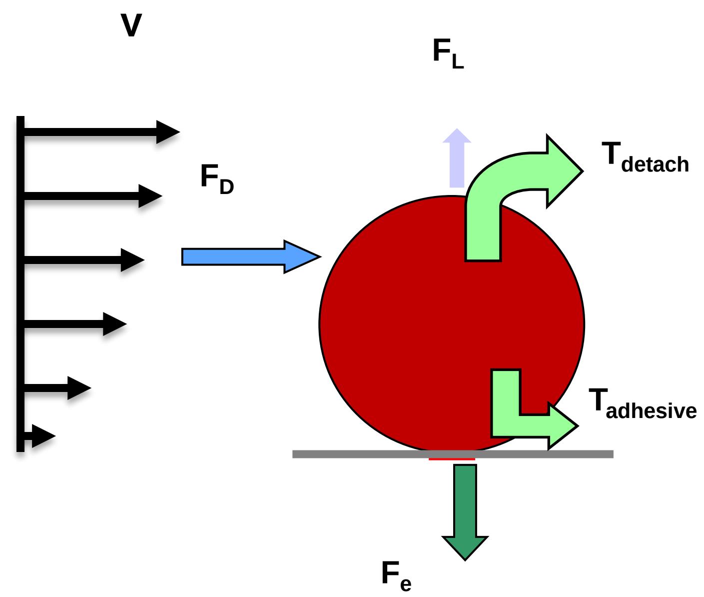
1. Packed glass beads
2. Colloids injection

•Elliptic equation excels the ADE in heterogenrous porous media.

•ADE with distributed filtration coefficients is sufficient for filtration in homogeneous porous media.

•Published as a journal paper in [3].

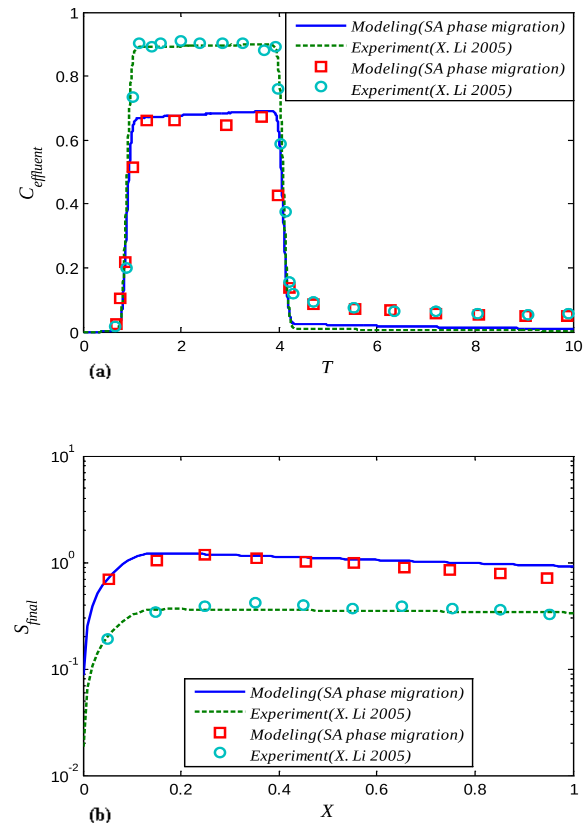
Task 02: Non-monotonic deposition profiles



Torque balance determines whether the attached particles will stay or be re-entrained by the bulk fluid.

Aggregates may form and release.

A new model for non-monotonic deposition[4]



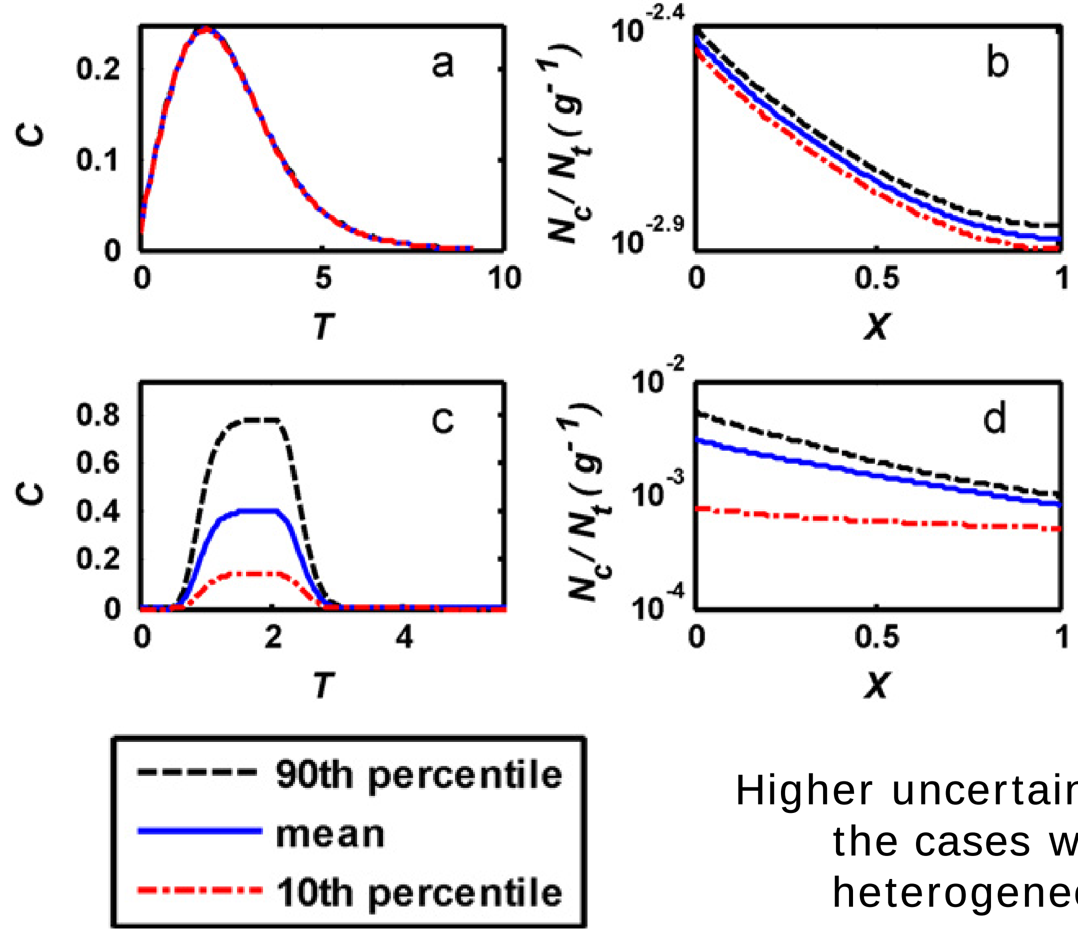
1. Migration of surface-associated particles due to weak assoc" + "itation.
2. Aggregates formation can also produce non-monotonic deposition.
3. A third particle population is sufficient for modeling non-monotonic deposition.

•Published as a journal paper in [4].

Task 03: Uncertainty and sensitivity analysis of filtration models

Uncertainty and sensitivity analysis	Filtration models	Experimental data
• Linear error propagation • Monte Carlo procedure • Differential analysis-local sensitivity • Regression of Monto Carlo simulations	• Elliptic equation • CTRW equation • Distribution of filtration coefficients	• Uniformly pakced glass beads • Uniformly Packed sands • Non-uniformly packed sands • Tracer or colloids injection

Uncertainty analysis with Monte Carlo simulations[5]

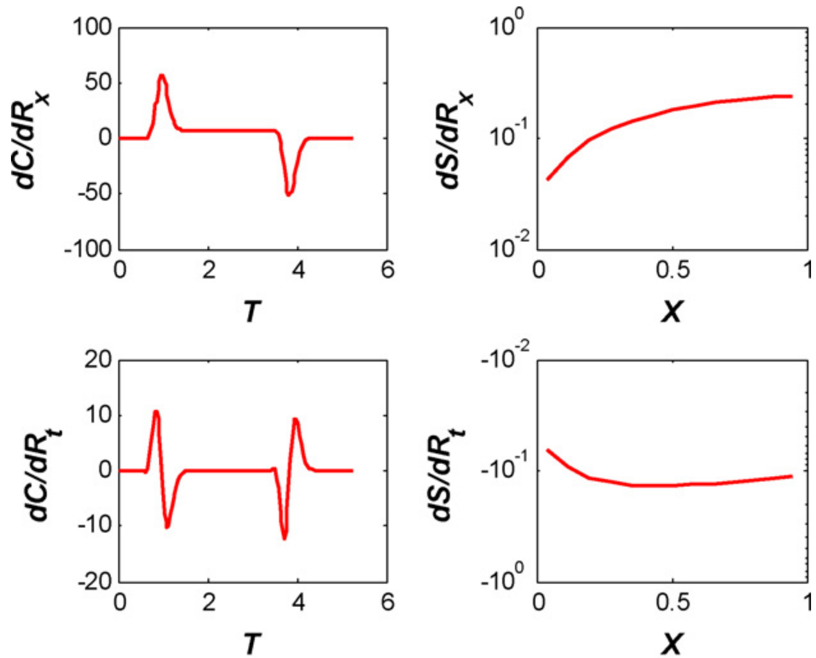


Monodisperse suspension

Polydisperse suspension

Higher uncertainties are observed in the cases with more heterogeneous colloids.

Local sensitivity & differential analysis[5]



C--effluent concentration

S--deposition

R_t--temporal dispersion

R_x--normal dispspersion

1. More measurements around the breakthrough and the end of injection are suggested to determine the dispersion coefficients more accurately.
2. Temporal dispersion contributes to deposition hyperexponentiality and spatial dispersion compensates this effect.

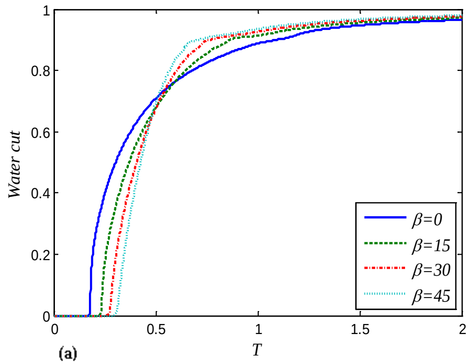
•Published as a journal paper in [5].

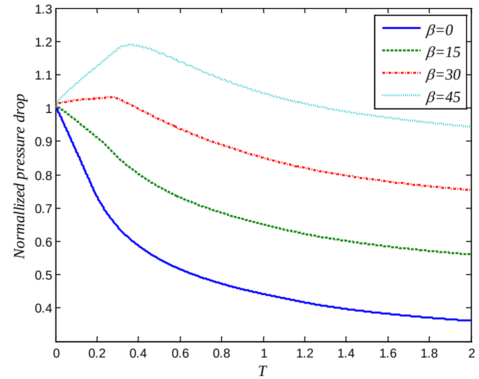
Task 04: Induced fines migration by low salinity waterflooding

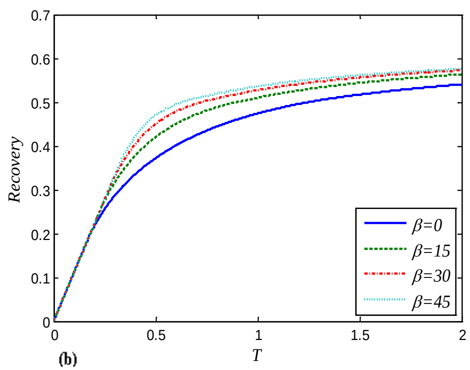
Torque balance analysis→
Express maximum retention
as a function of:

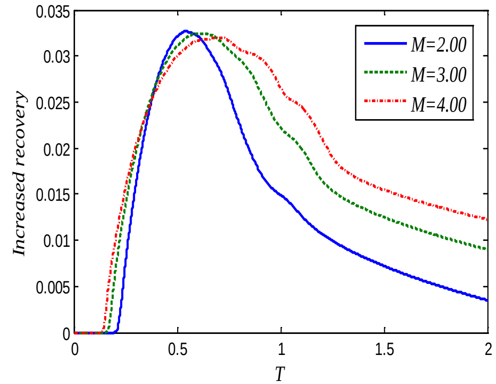
1. Water salinity
2. Water velocity
3. Particle size
4. …

Low salinity waterflooding in communicating layer-cake reservoirs[6,7]









Here β is the formation damage coefficient.

1. Water cut is decreased.
2. Oil recovery is increased.
3. More energy for the pressure drop is required.
4. Higher mobility ratio facilitates the fluid diversion caused by fines migration.

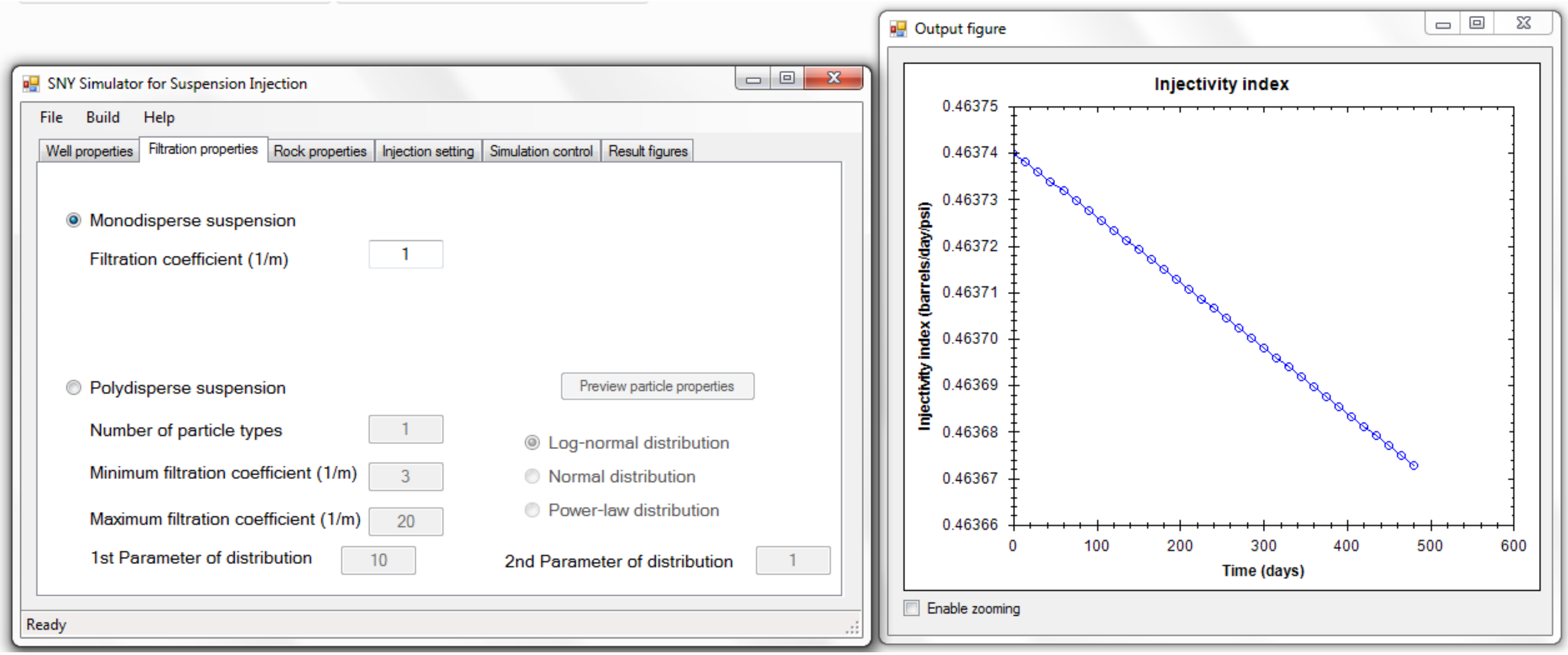
•Submitted as 2 journal papers in [4].

Task 05: Review of stochastic approaches to modeling suspension flow in porous media

Population balance approaches	Continuous time random walk approaches	Elliptic equation approaches
• Particle flow kinetics • Particle capture kinetics • Pore plugging kinetics • Averaging integral-differential equations	• Microscopic-scale random motions of particles • Expressions in Laplace space • Memory function with residence time disitrbution	• Microscopic-scale random motions of particles • Elliptic equation with temporal dispersion term • Coupled with population balance approach

Accepted as a book chapter [8]

Task 06: Software development for waterflooding with solids filtration



- Distribution of filtration coefficients
- Elliptic equation for non-Fickian transport
- 1-D linear injection and axis-symmeric radial injection
- Formation damage and injectivity decline of injection wells

Future tasks

1. More modules in the software accounting for external cake formation, perforations, horizontal injection wells.
2. Optimization problems of low-salinity waterflooding: balance between energy consumption for pressure and increased oil recovery.
3. Application of percolation theory for suspension flow in porous media.

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Thank you for your attention!

Questions?